



# Hydrologic Ensemble Prediction for Risk-Based Water Resources Management and Hazard Mitigation

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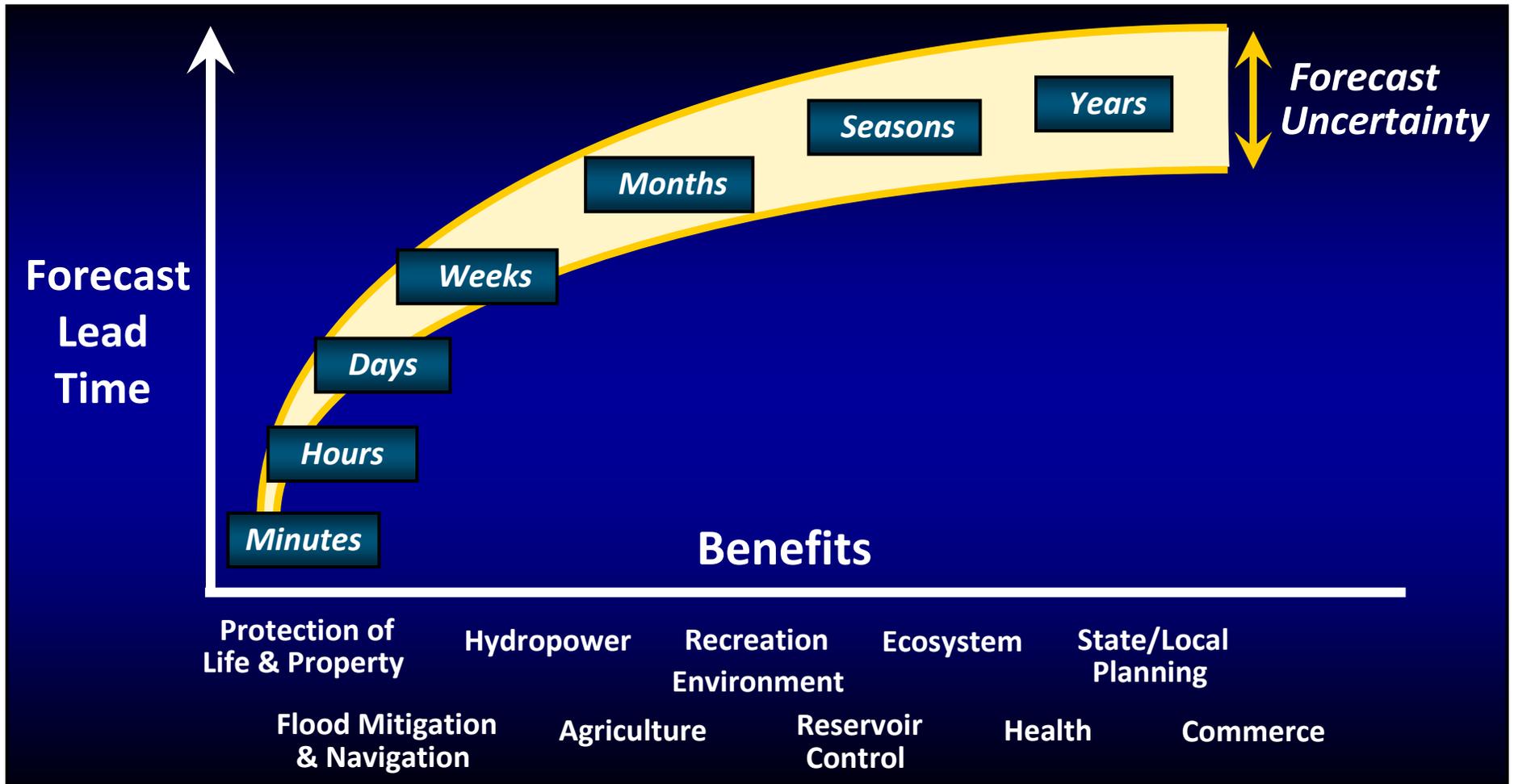
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# Products & Services Goal

Seamless probabilistic forecasts for all lead times



# Why hydrologic ensemble forecasting?

- Provide an estimate of the forecast (i.e. *predictive*) uncertainty
  - Confidence information (for the forecasters)
  - For user-specific risk-based decision-making (for the customers)
- Improve forecast accuracy
  - An (optimally weighted) average of two good (or bad) forecasts is better than either of the two
- Extend forecast lead time
  - Weather and climate forecasts are highly uncertain and noisy; they cannot practically be conveyed as single-valued
- Cost-effective improvement of forecast systems, science and process

# NWS Hydrologic Ensemble Forecast System (HEFS)

- An end-to-end hydrologic ensemble forecast system currently under development
- Comprehensive plan developed in 2007 ([http://www.weather.gov/oh/rfcdev/docs/XEFS\\_design\\_gap\\_analysis\\_report\\_final.pdf](http://www.weather.gov/oh/rfcdev/docs/XEFS_design_gap_analysis_report_final.pdf))
- NWS/OHD collaborating with RFCs, Deltares, NCEP, OAR and universities through:
  - Advanced Hydrologic Prediction Service (AHPS)
  - Climate Prediction Program for the Americas (CPPA) Core Project
  - The Observing-System Research and Predictability Experiment (THORPEX)
  - The Hydrologic Ensemble Prediction Experiment (HEPEX)
  - Research grants
- Field deployment via the Community Hydrologic Prediction System (CHPS)
- Prototype components under testing and evaluation at a number of RFCs
- Additional prototype deployments during the next 2 years

# Current (Seasonal ESP) vs. HEFS

Feature	Current	HEFS
Platform	National Weather Service River Forecast System (NWSRFS) (inflexible, outdated)	Community Hydrologic Prediction System (CHPS) (flexible, SOA)
Forecast horizon	Weeks to seasons	Hours to years
Input forecasts	Climate outlook forecasts	Short-, medium- and long-range forecasts (HPC/RFC, GFS, CFS, SREF)
Hydrologic uncertainty	Not addressed	Addressed (but w/ room for improvement)
Products	Limited number of graphical products	A wide array of user-tailored products via Web-enabled interactive toolbox

# Uncertainty integration strategy

$$f_1(q_f | q_o) = \int f_2(q_f | q_o, s_f) f_3(s_f | q_o) ds_f$$

**Predictive  
uncertainty in  
streamflow**

**Residual hydrologic  
uncertainty**

**Uncertainty in  
model-predicted  
streamflow**

where  $q_f$  Streamflow at some future times  
 $q_o$  Observed flow up to and including the current time  
 $s_f$  Model-predicted streamflow at the future times

Krzysztofowicz (1999)

$$f_3(s_f | q_o) = \iiint f_4(s_f | b_f, i, p, q_o) f_5(b_f | i, p, q_o) f_6(p | i, q_o) f_7(i | q_o) db_f di dp$$

**Uncertainty in  
model-predicted  
streamflow**

**Conditional hydrologic  
model simulation**

**Future forcing  
uncertainty**

**Parametric  
uncertainty**

**Initial condition  
uncertainty**

where  $b_f$  Future boundary conditions (precipitation, temperature)  
 $i$  Initial conditions  
 $p$  Model parameters

Seo et al. (2006)

# Uncertainty integration strategy (cont.)

w/o data assimilator and parametric uncertainty processor

$$f_1(q_f | q_o) = \int f_2(q_f | q_o, s_f) f_3(s_f | q_o) ds_f$$

**Predictive uncertainty in streamflow**      **Residual hydrologic uncertainty**      **Uncertainty in model-predicted streamflow**

where  $q_f$  Streamflow at some future times  
 $q_o$  Observed flow up to and including the current time  
 $s_f$  Model-predicted streamflow at the future times

$$f_3(s_f | q_o) = \int f_4(s_f | b_f) f_5(b_f) db_f$$

**Uncertainty in model-predicted streamflow**      **Conditional hydrologic model simulation**      **Future forcing uncertainty**

where  $b_f$  Future boundary conditions (precipitation, temperature)

# Strategy for forcing ensembles

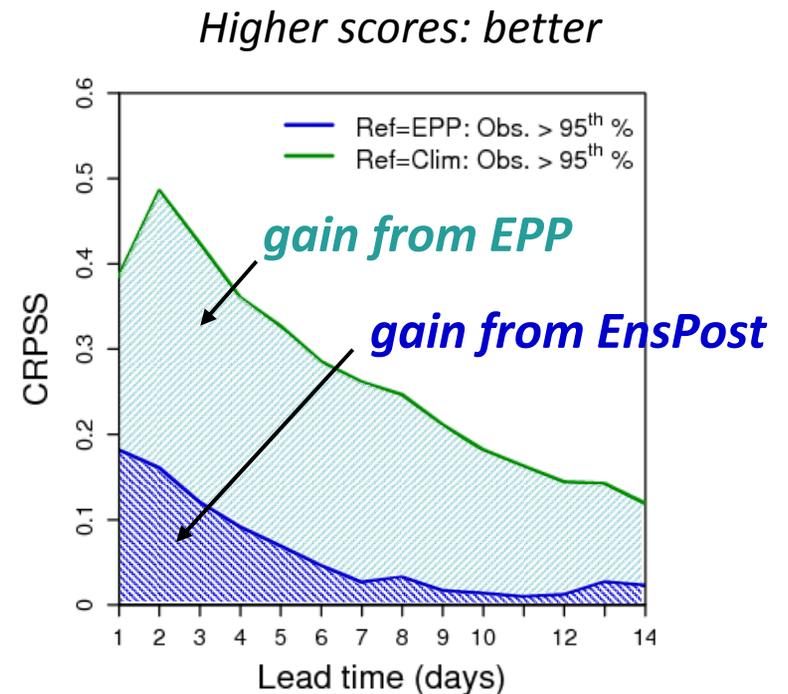
- Current
  - Generate ensembles statistically from the single-valued QPF and QTF
    - HPC/RFC, GFS, CFS
    - Ensemble Pre-Processor (EPP)
      - Schaake et al. (2007), Wu et al. (2010)
- Near-term plan
  - (Post-processed) Multi-model ensembles
    - Currently in experimental operation at some RFCs using MMEFS
  - Include potential evaporation

# Strategy for hydrologic uncertainty modeling

- Current
  - Lump all hydrologic uncertainties into one and model it stochastically (Seo et al. 2007)
- Near-term plan
  - Uncertainty modeling of regulated flows
  - Initial condition uncertainty via ensemble data assimilation
  - Parametric uncertainty via the parametric uncertainty processor
  - Multimodel ensembles

# Verification Results: EPP-ESP-EnsPost flow forecast compared to climatological ESP

- Skill Score for Mean CRPS (CRPSS): GFS-based flow generated by EPP-ESP-EnsPost compared to GFS-based flow (EPP-ESP) and climatology-based flows (climatological ESP)
- Very large improvement by EPP-ESP over climatological ESP
- Significant improvement by EPP-ESP-EnsPost over EPP-ESP

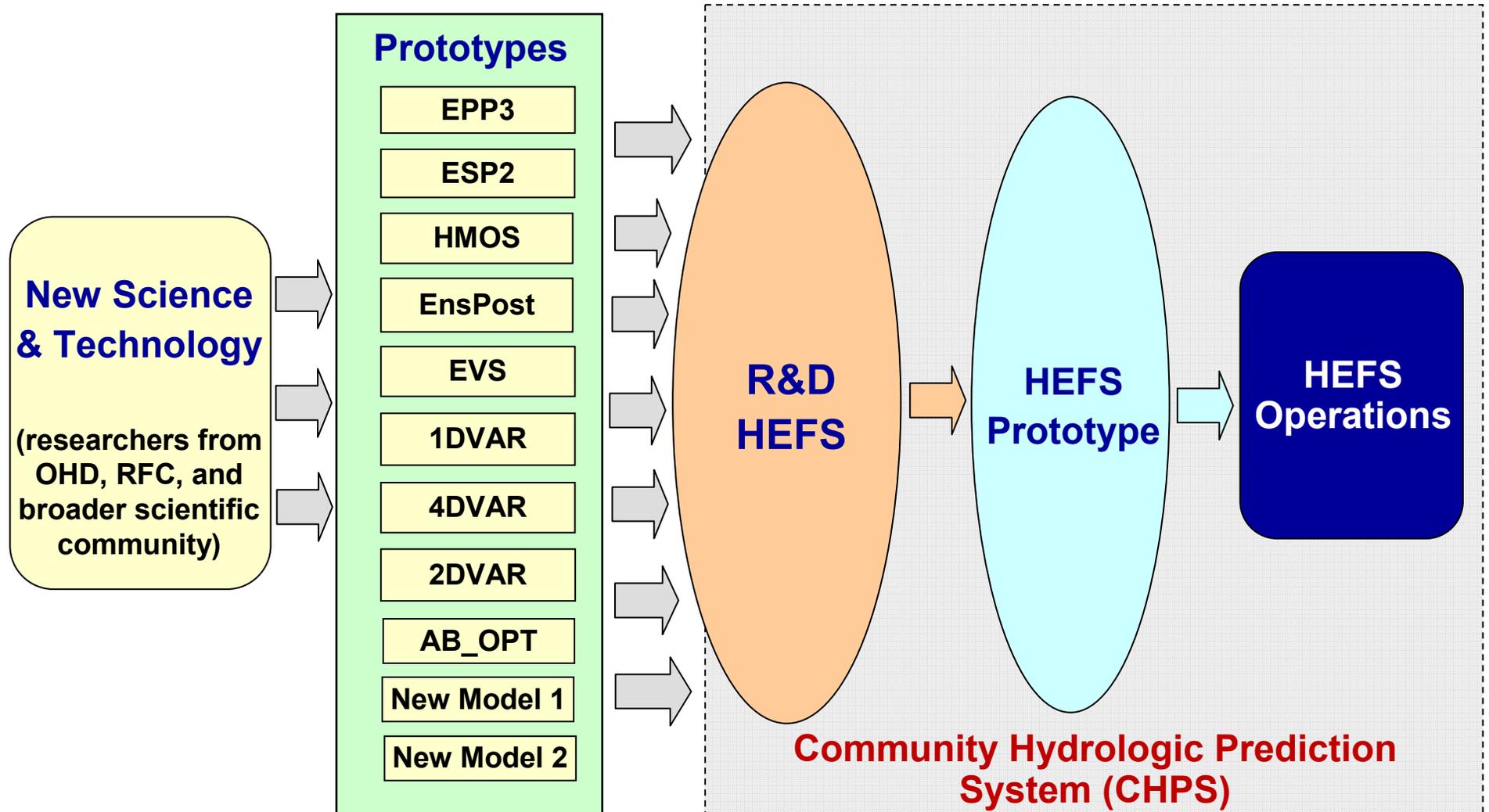


# Operational hydrologic ensemble forecasting - Challenges

- Appropriately model and integrate uncertainties introduced from data, model, and human sources
- Combine ensemble forcing for short, medium, and long ranges from multiple sources
- Maintain spatiotemporal relationships across different scales
- Include forecaster skill in short-term inputs (QPF, temperature, etc.)
- Include forecaster guidance of hydrologic model operation
- Maintain coherence between deterministic and ensemble forecasts
- Provide uncertainty information in a form and context that is easily understandable and useful to the customers
- Reduce the cone of uncertainty for effective decision support
  - Improve accuracy of meteorological and hydrologic models
- Improve uncertainty modeling and observations of rare and extreme events (e.g. record flooding, drought)
  - Extreme conditions may be outside of model limits and without historical analog
- Greatly improve computing, database and data storage capabilities

Adapted from  
Hartman (2007)

# Collaborative R&D and RTO in the CHPS environment





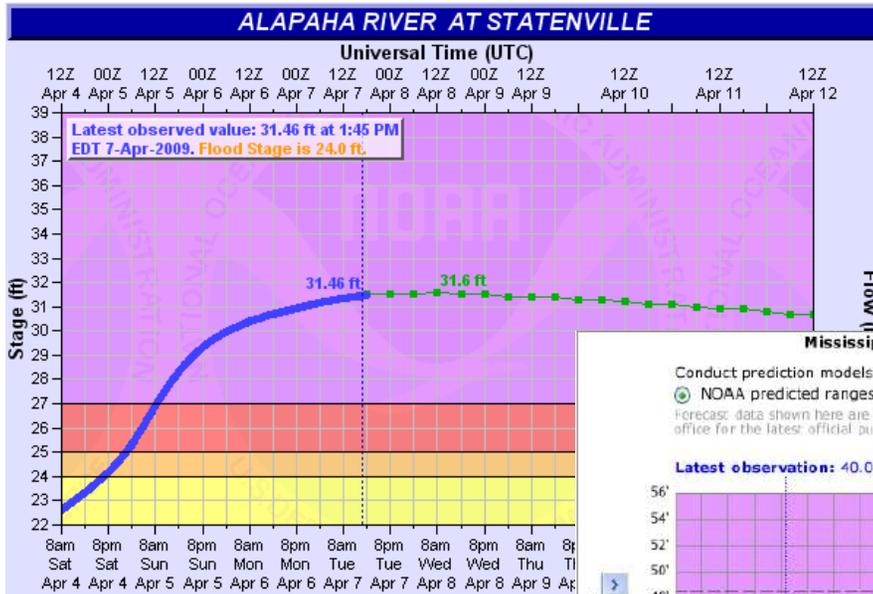
# Thank you

For more information:  
[julie.demargne@noaa.gov](mailto:julie.demargne@noaa.gov)



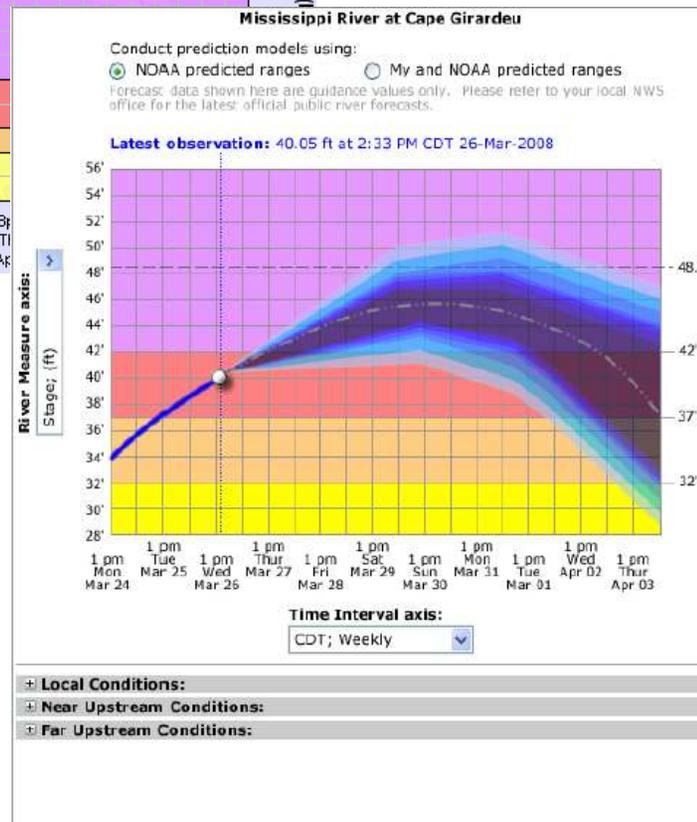
# Hyperlinked slides

# Provide an actionable estimate of the forecast (i.e. *predictive*) uncertainty



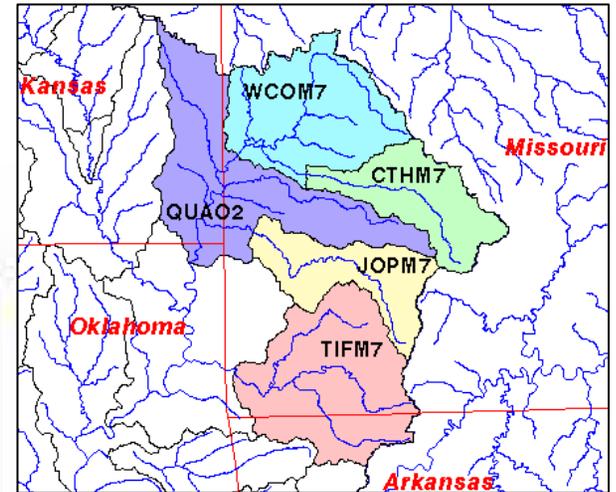
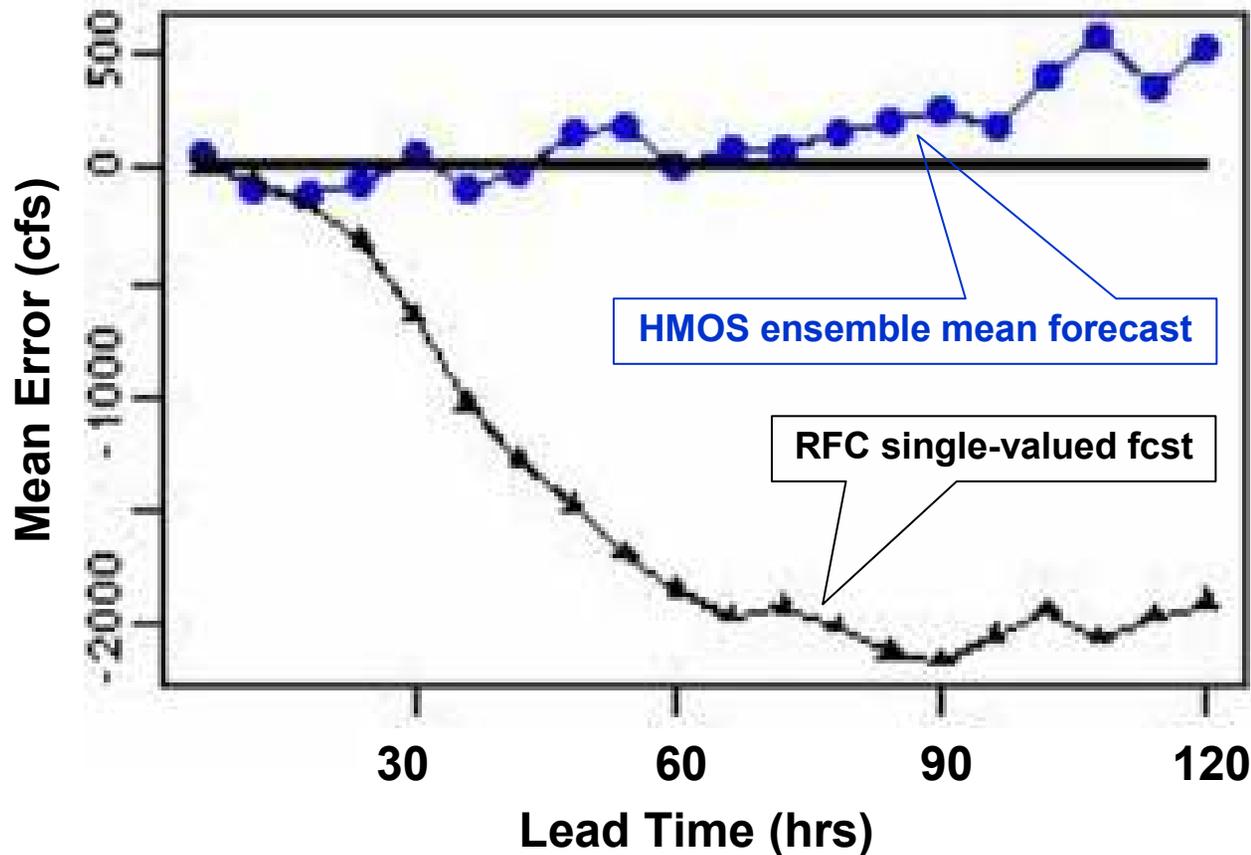
Current product

## With ensemble forecasting

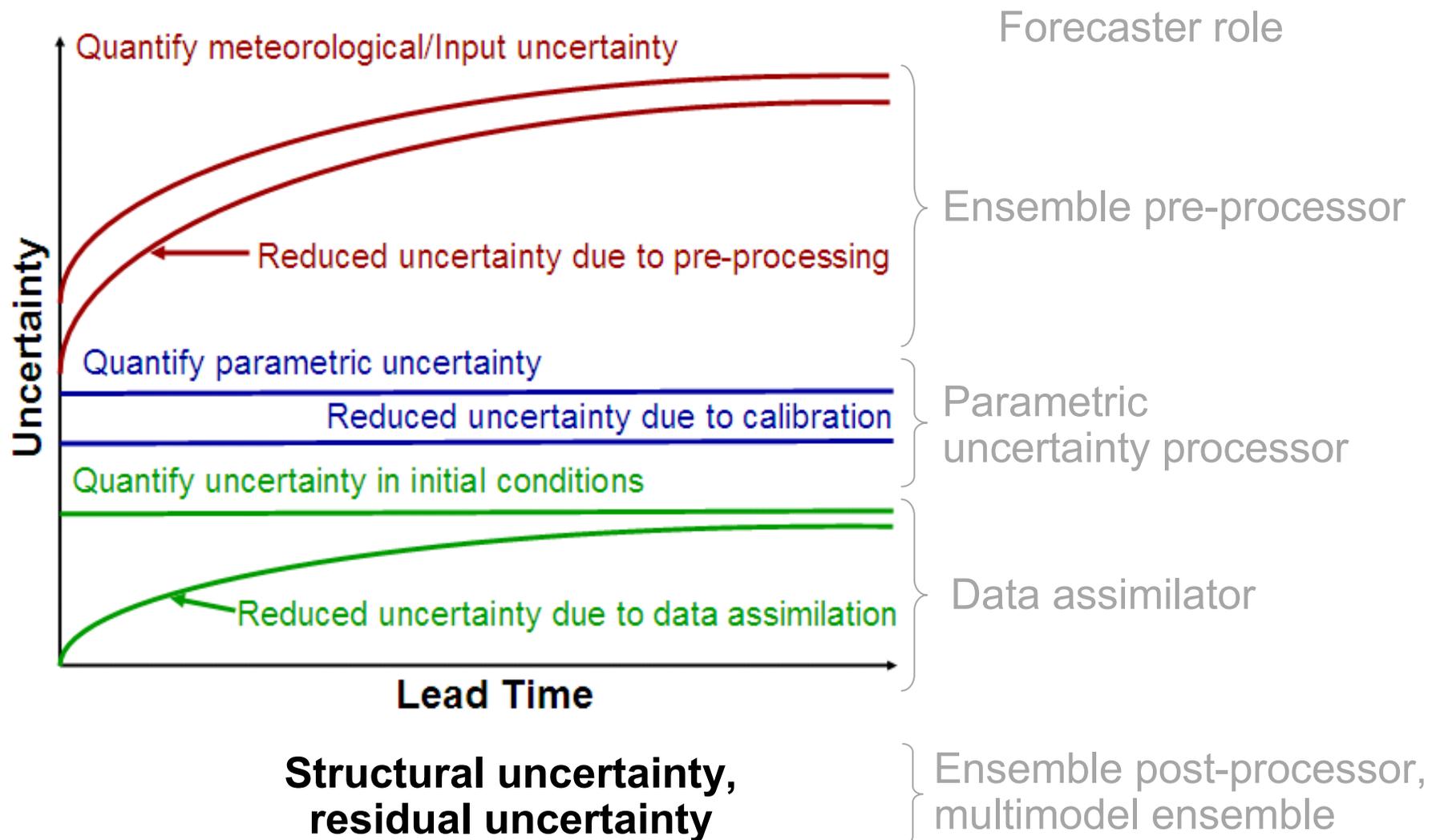


In single-valued forecast process, “hydrologic error-tolerable” lead time for QPF is very limited

### QUAO2 – High flow



# Uncertainties in hydrologic forecast



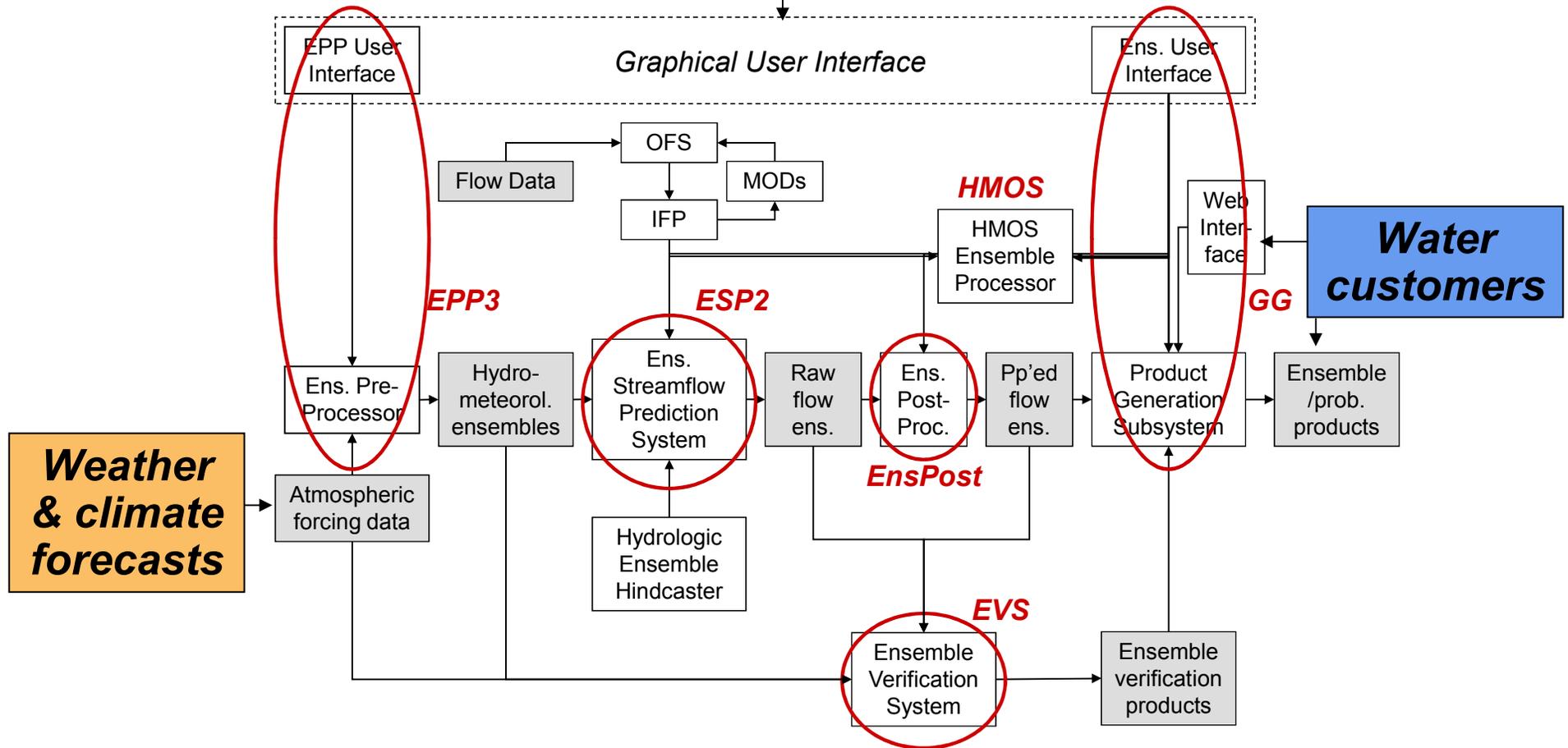
**Flow regulations** - A large challenge



# Hydrologic Ensemble Forecast System (HEFS)



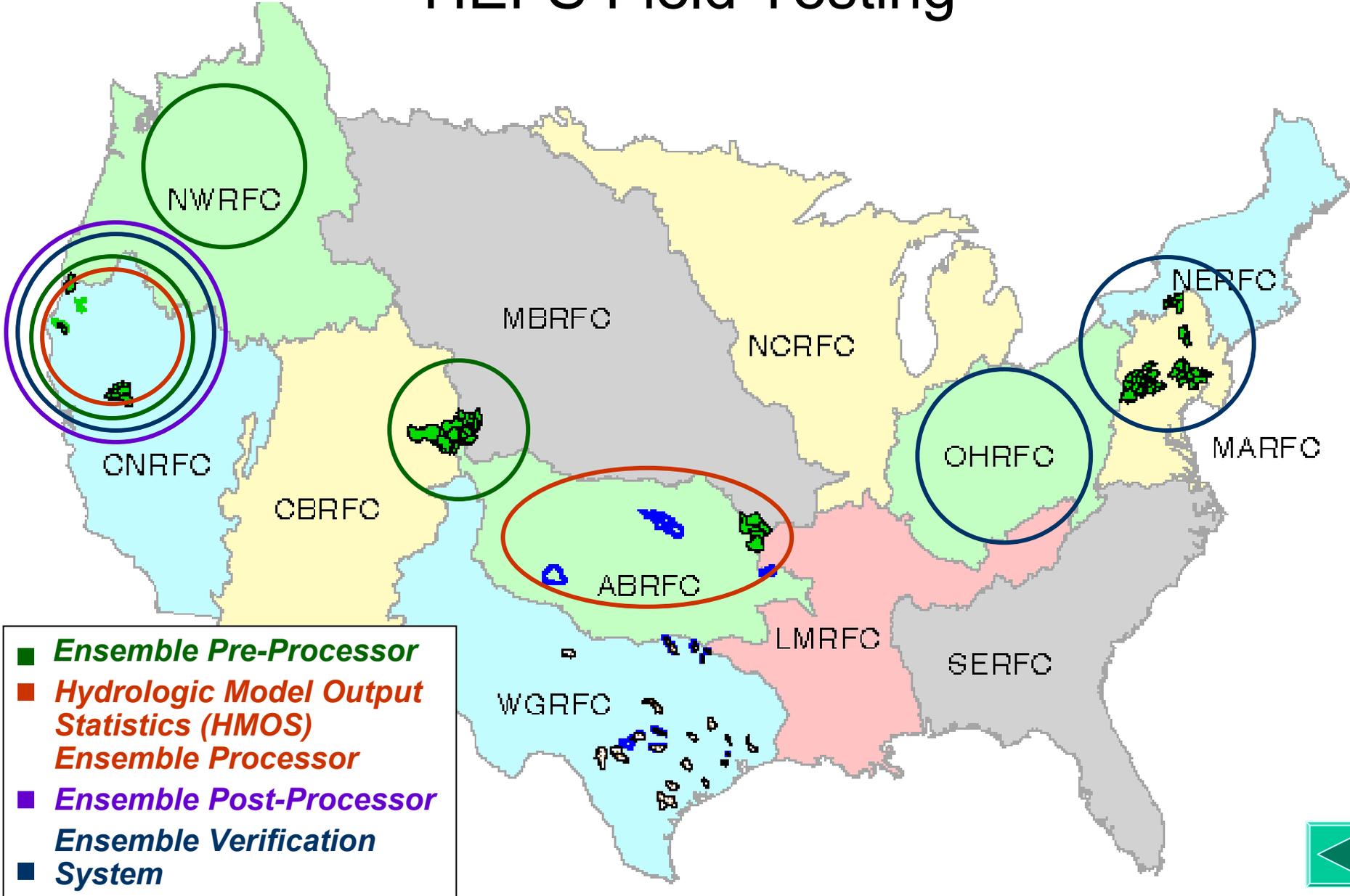
Forecasters add value



HEFS will enable seamless hydrologic ensemble prediction from weather to climate scales and translate weather and climate prediction into uncertainty-quantified water information

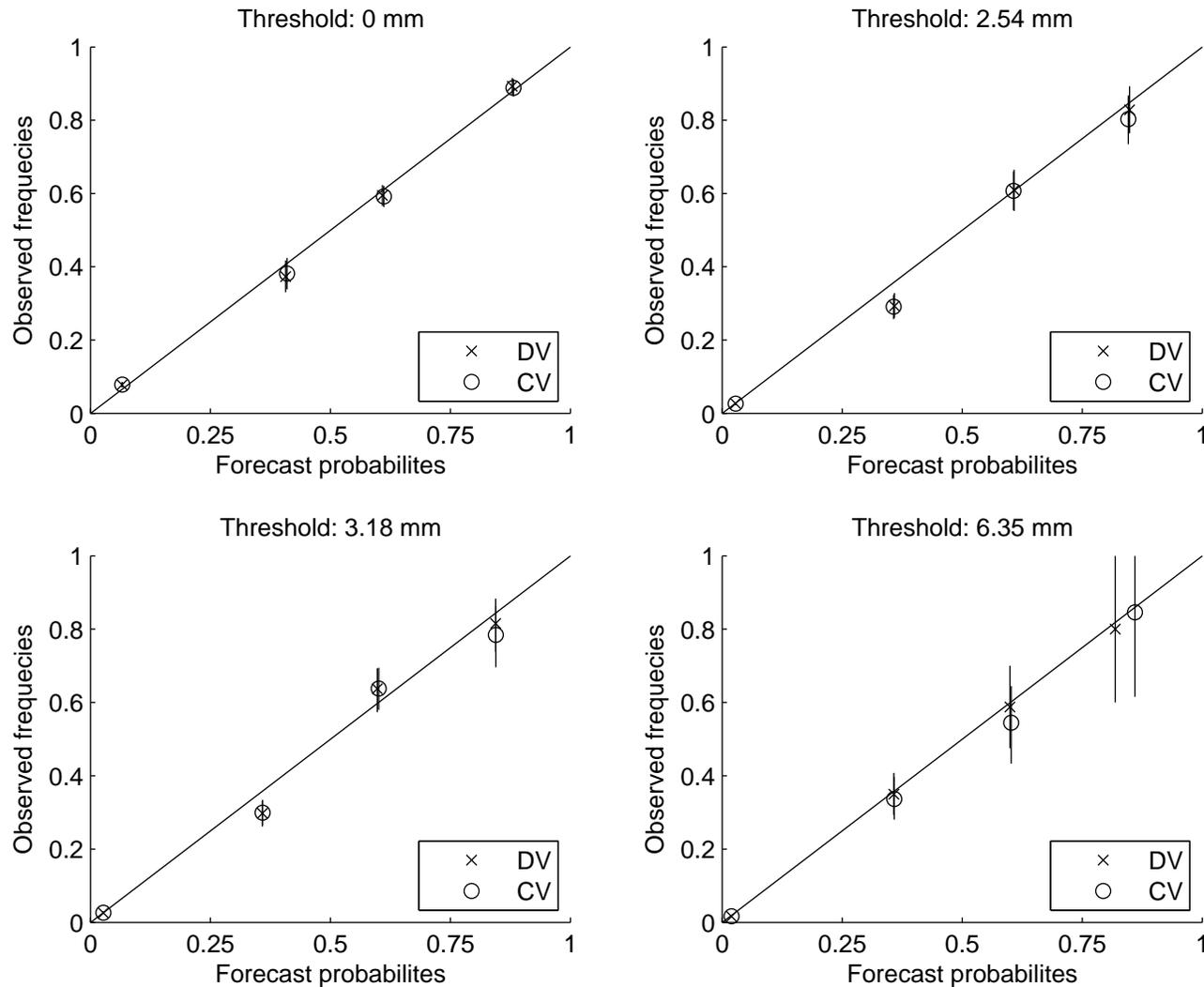


# HEFS Field Testing



# EPP-generated precipitation ensembles

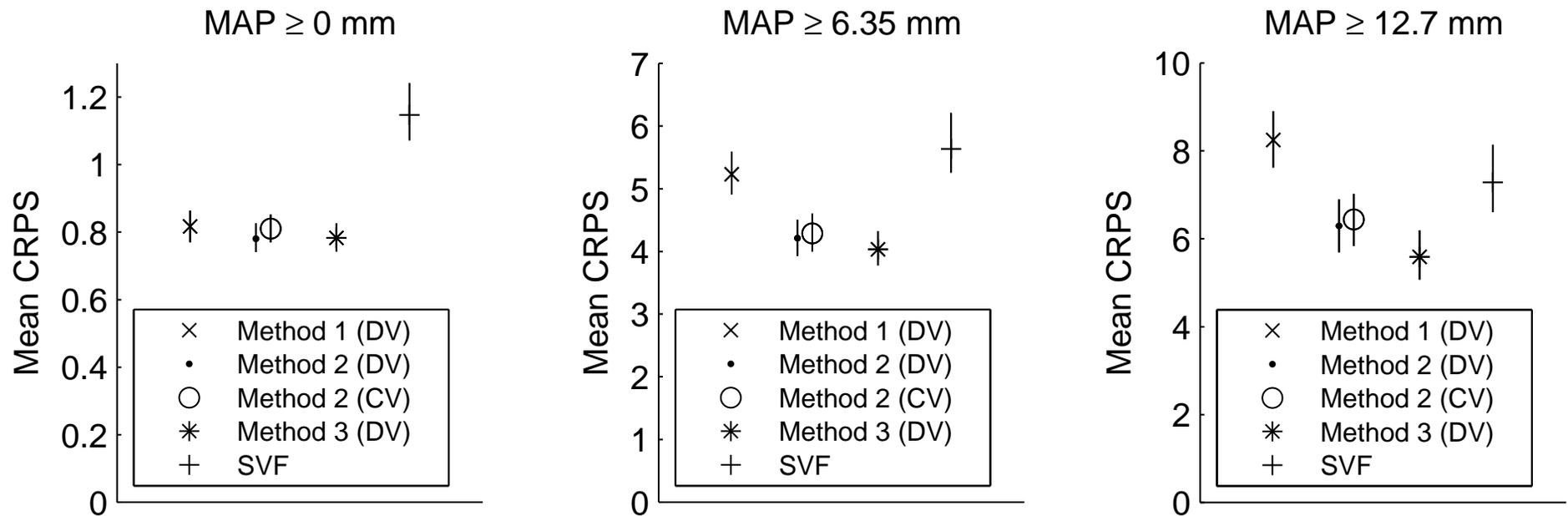
Reliability diagrams for ensemble hindcasts of 6-hr precipitation for all 6-hr periods in Day 1 for Huntingdon in central PA. The vertical bars denote 95% confidence interval.



From Wu et al. (2010)

# EPP-generated precipitation ensembles (cont.)

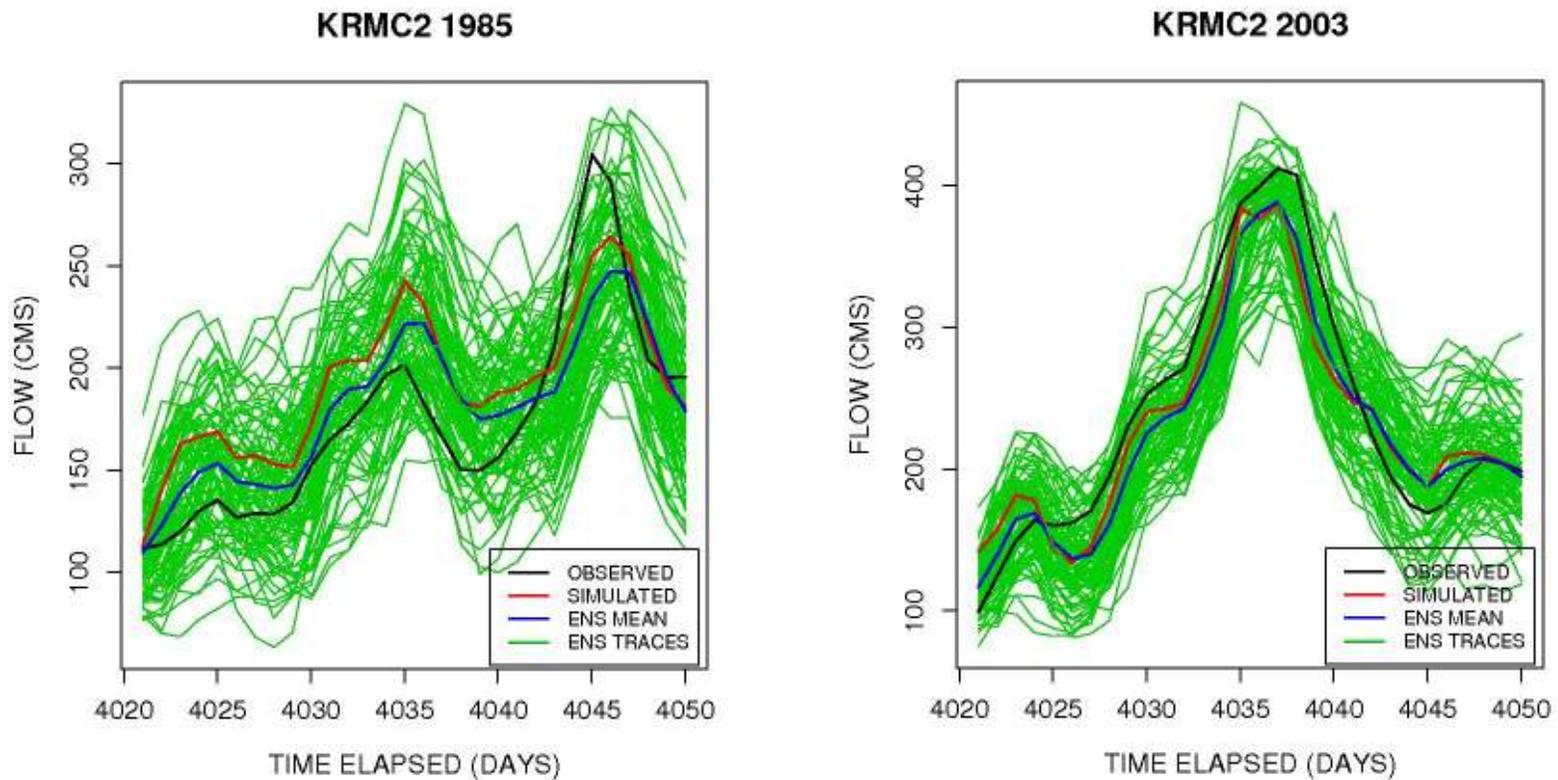
Mean CRPS for ensemble hindcasts of 6-hr precipitation for all 6-hr periods in Day 1 for Nov through Apr. The results are for the North Fork of the American River in CA, with upper and lower areas combined. The vertical bars denote the 95% confidence intervals.



From Wu et al. (2010)

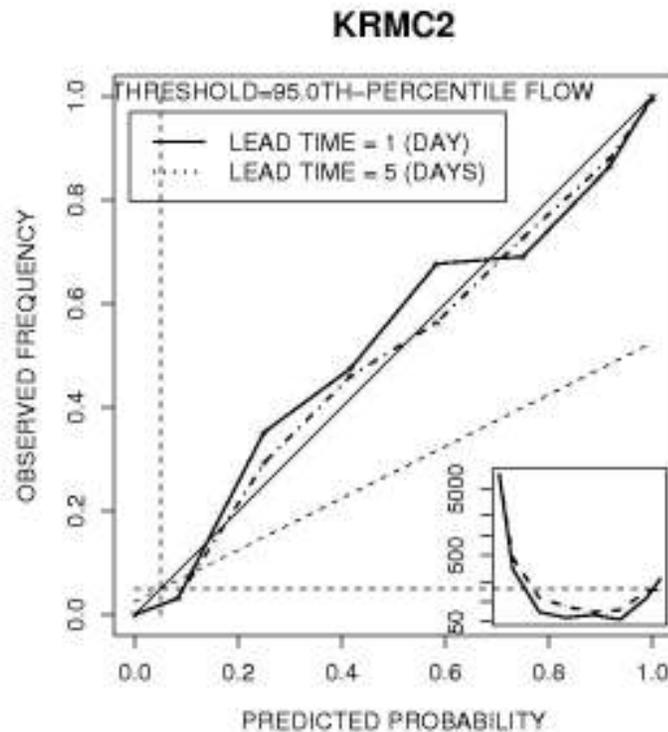


# Post-processed streamflow ensembles daily flow

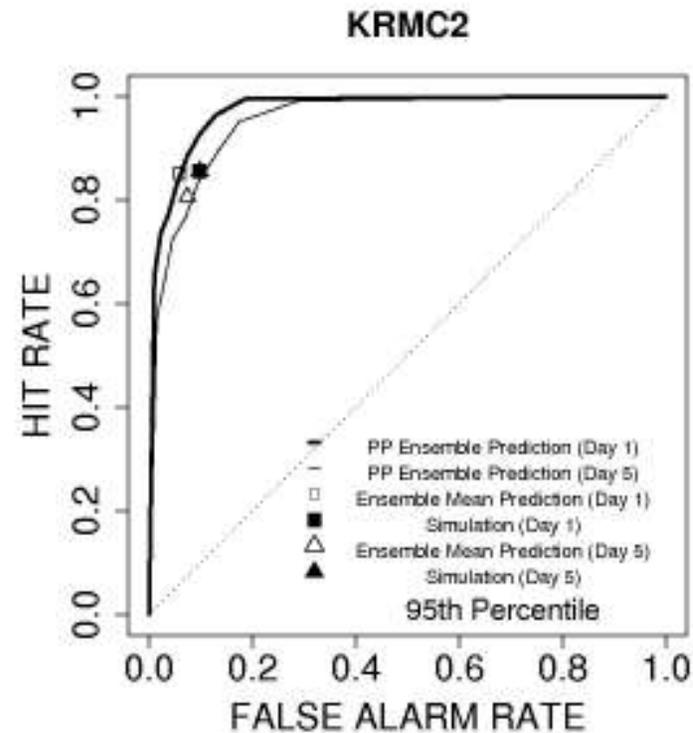


In general, the post-processed ensemble members consistently encompass the verifying observation, and the ensemble mean closely resembles the single-valued forecast

# Verification of post-processed streamflow ensembles – daily flow

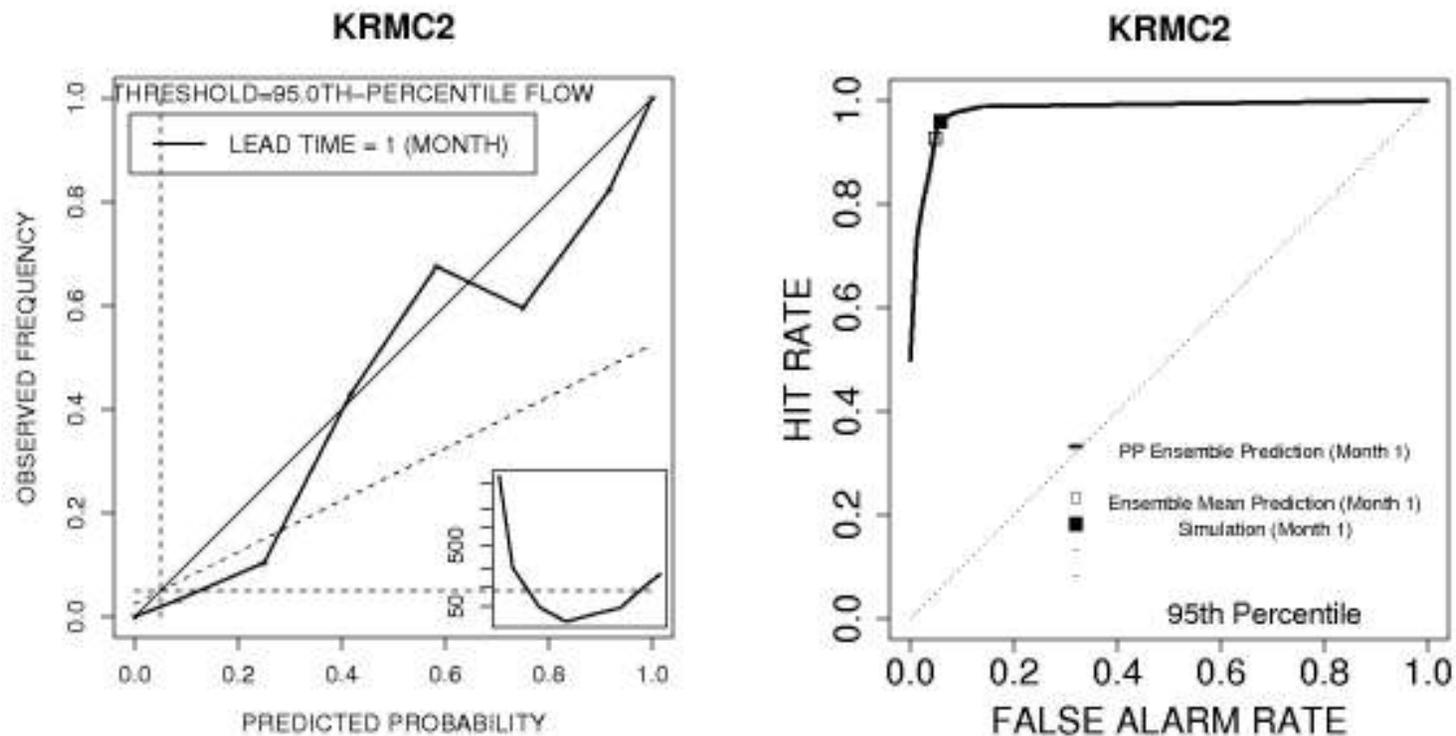


Reliability Diagram



Relative Operating Characteristics (ROC)

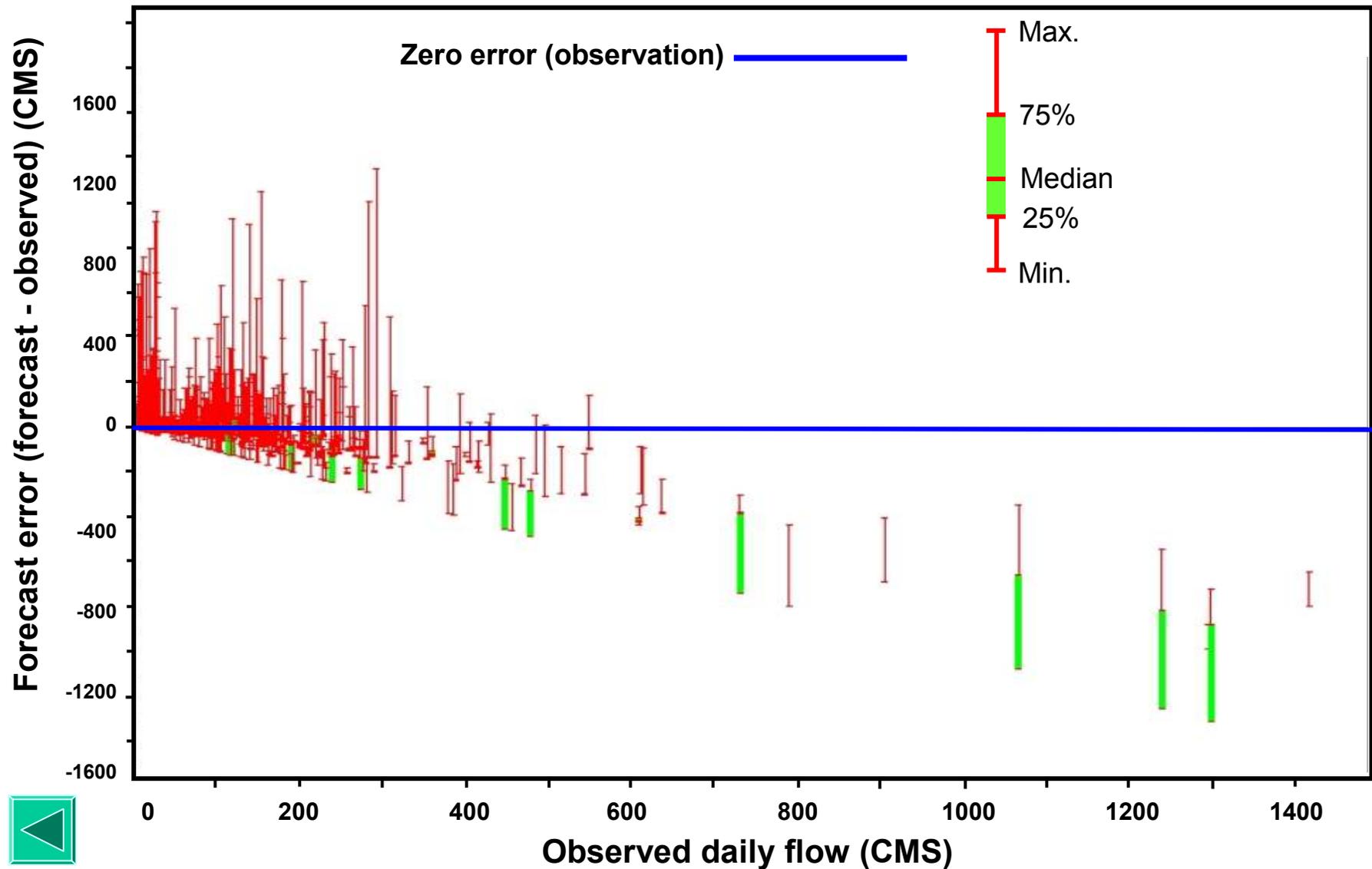
# Verification of post-processed streamflow ensembles – monthly flow



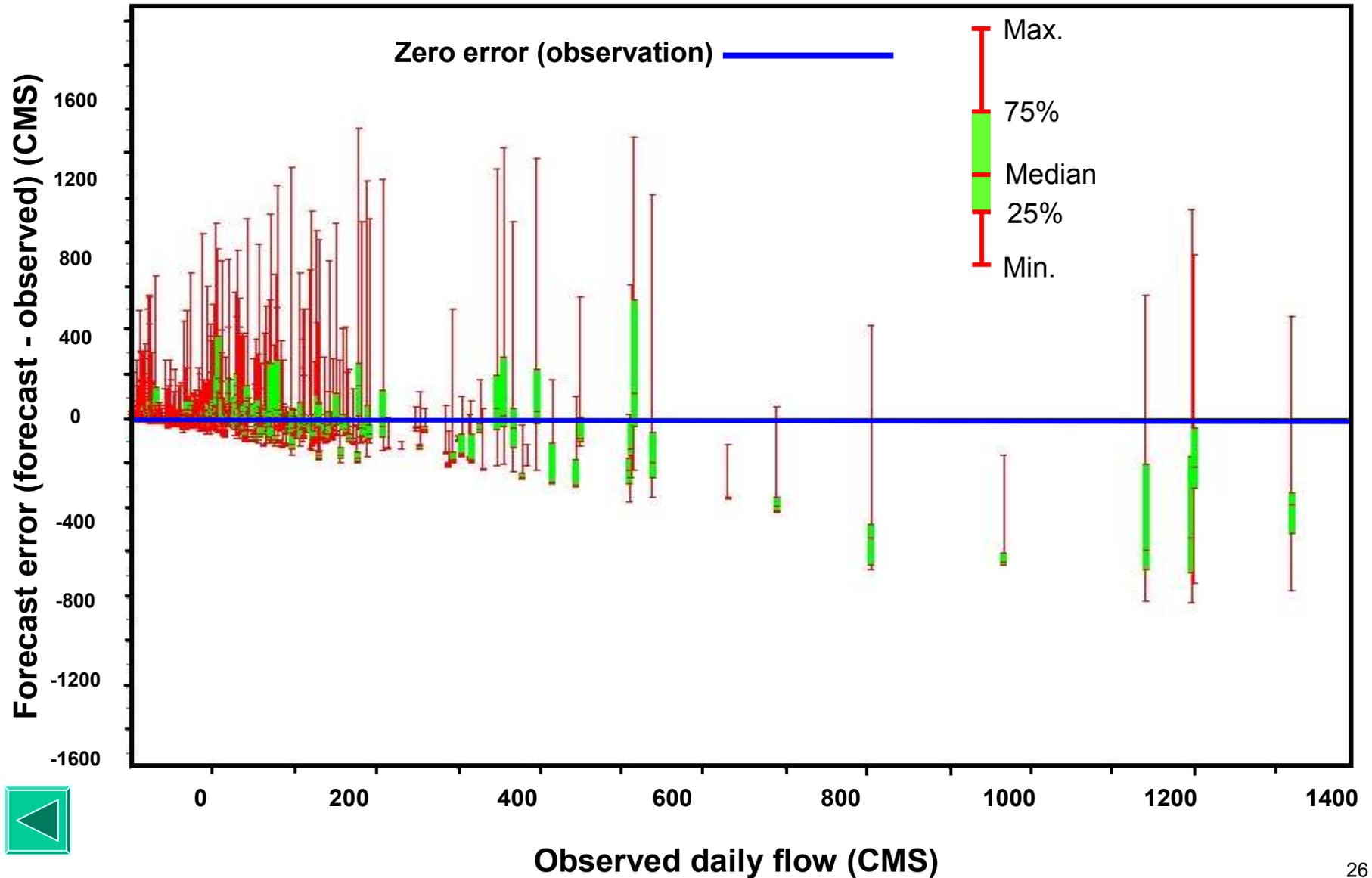
In general, post-processed streamflow ensembles are reliable and as skillful, in the mean sense, as the operational single-valued forecast over a range of temporal scale of aggregation



# Errors in Climatological ESP Forecast (Day 1)



# Errors in GFS-based EPP-ESP-EnsPost Flow Forecast (Day 1)





# End of slides